INDUSTRIAL ILLUMINATION

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INDUSTRIAL ILLUMINATION

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OBJECT

In writing this thesis, it has been the object, as a result of the writer's experience, to set forth the reasons for the importance of industrial illumination and to point out in detail the factors to be taken care of in designing lighting systems.

The illuminating engineer generally has a knowledge of the laws of light, but before he can design reflectors, it is necessary that he be intimately acquainted with the operations entering into the manufacture of steel reflectors.

A brief description of these processes are, therefore, given, after which the problems met with in designing industrial units are discussed.

INDUSTRIAL ILLUMINATION

During the last few years, greatly increased attention has been paid to the lighting of industrial plants. As a result of this increased attention, considerable progress has been made in the art of industrial lighting.

Since enormous sums have been spent in installing these systems it is apparent that the industrial lighting system plays an important part in the manufacturing industry.

Before going into the general subject of lighting, it is, therefore, advisable to review the reasons why good industrial lighting is a necessity.

AMOUNT OF DAYLIGHT ANNUALLY

The diagram under figure 1, is made up of data secured from the Weather Bureau reports and makes it possible to immediately visualize the actual amount of clear daylight

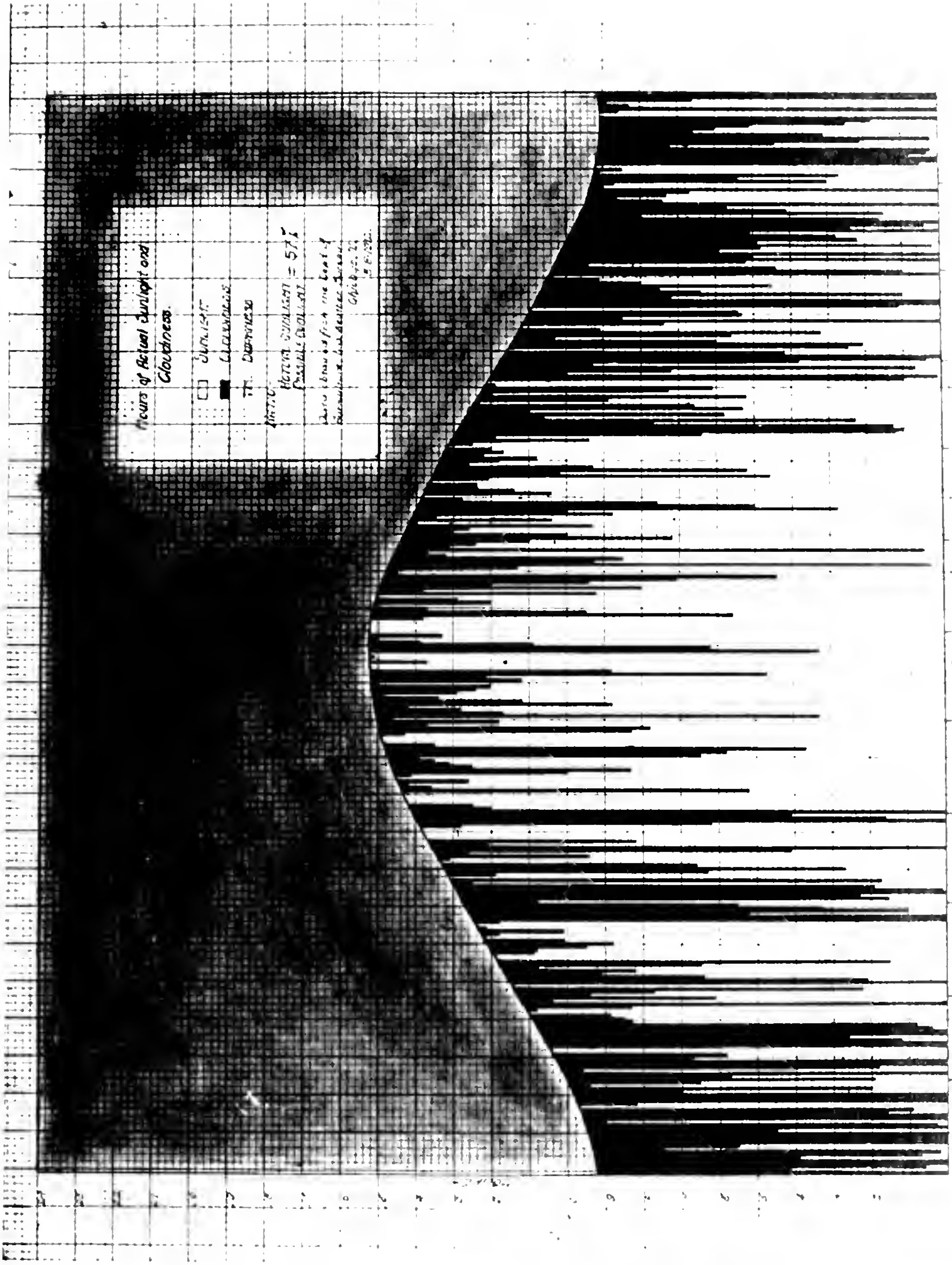


Figure 1

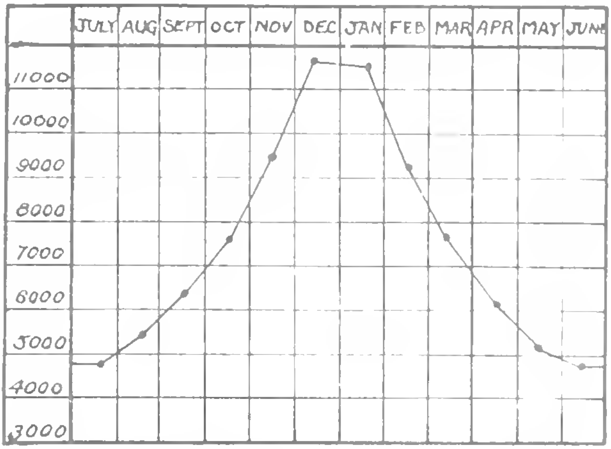
during the year. The shaded portion of the diagram indicates absolute darkness; the partly shaded indicates cloudiness while the clear shows the actual time that good daylight was available.

This makes it apparent that we have good daylight but a very small percentage of the year so that it is extremely essential, particularly when manufacturing plants are operating more than eight to ten hours a day, that careful attention be paid to the artificial lighting system.

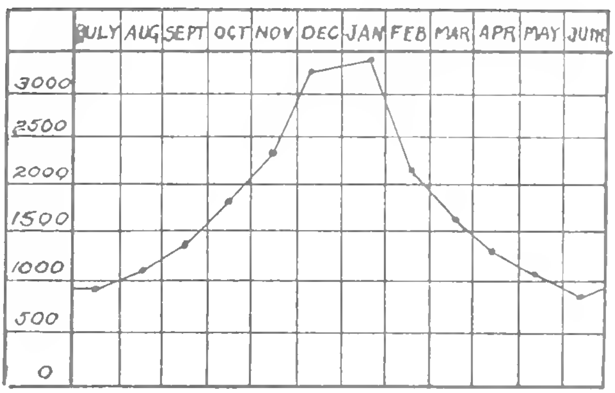
ACCIDENTS

Protection against accidents must be provided, whether one views the subject from either humanitarian or economic standpoints.

Figure 2, is taken from a paper presented before the Illuminating Engineering Society on the subject of "Illumination and One Year's Accidents." The diagram



Seasonal distribution of all industrial
accidents for the year.



Seasonal distribution of all industrial
accidents caused by inadequate illumination.

Figure 2

clearly indicates that the accidents are far greater during the period of short days in the winter than they are in the longer days during the summer months.

Under the noisy conditions which usually prevail in a factory, vision is the one sense which is really effective in avoiding belts, moving machinery and other dangers; and it is the unseen which almost always causes injury. By illuminating such places as these, the danger is largely eliminated.

In manufacturing plants where the lighting intensity is insufficient, where the shadows are sharp and dense and where there is glaring or flickering light sources, there is usually a long list of accidents during the dark hours.

The various insurance companies have taken considerable data on the subject of the relation of accidents and good illumination and its importance is emphasized by the amount

of literature which they have published on the subject. The Traveler's Insurance Company in a report states that there were 91,000 accidents in and about industrial plants during the year 1910. Of this total number 23.8% could be traced directly or indirectly to the lack of proper illumination.

The Iron Age in an editorial stated that an analysis of accidents recorded under the British Workman's Compensation System shows that something like 25% of the total may be attributed to insufficient lighting of industrial plants. The accidents were in a great number of cases not due to a lack of insufficient total candle power but were due to the fact that the light was not well distributed. Large machinery may cause shadows and it is essential that a sufficient amount of, as well as large enough, lighting units be used.

Various State Legislatures are

slowly adopting "Codes" of lighting for industrial plants. The Illuminating Engineering Society, through a combination of committees, has written a "Code of Lighting" which has been brought before a number of State Legislatures. The state of Wisconsin has adopted a code of its own. The state of New Jersey has adopted the one put out by the Illuminating Engineering Society and the state of Pennsylvania has prepared a comparatively simple code which will no doubt be extended and made more adequate in time.

There has been much discussion in the Courts as to what constitutes adequate lighting, but repeated decisions, however, have been made to the effect that poor lighting is "contributing negligence" on the part of an employer.

Employers are every day beginning to look at the question of adequate artificial lighting, by considering the millions of

dollars which are spent annually to compensate employes for industrial accidents, which could have been prevented by good lighting. This same amount of money is sufficient to modernize the lighting of all the industrial plants in the country and it would, therefore, be actual economy if all plants would give closer attention to this feature of their equipment.

PRODUCTION

It is now conceded by engineers as well as manufacturers that production decreases when illumination becomes inadequate.

Many tests have been made to approve this point and one of the best examples is that of a large steel plant in Pennsylvania which showed an increase of 10% in the output of the night shift when the lighting system was modernized. To prove that this increased production was due to better illumination, the old lighting system was temporarily re-install-

ed and the new lighting system turned off. The production immediately fell back to the old rate but increased 10% again when the new lighting system was turned on.

It is not only important that there be adequate light but the equipment must be such that it does not require adjusting by the workmen a number of times a day.

In looking at the question of lighting from a standpoint of production, the writer has had some interesting experiences in going over industrial plants. A general average of the figures taken in various sized plants indicate that the cost of operation of the adequate lighting system is usually about 1% of the total compensation of the workman under the light. Figuring on the basis of a nine hour day, which amounts to 540 minutes, 1% would amount to 5.4 minutes. In other words, 5.4 minutes

work on the part of the employes each day is charged up against the lighting system. It may, therefore, readily be seen that if it is necessary for a workman to slow up sufficiently to lose about 6 minutes time per day due to poor lighting, the entire expense necessary to operate an adequate system is lost.

Observation in various plants will often indicate that workmen lose from 1/2 to 2 hours per day due to poor lighting. On the basis of figures given in the foregoing, if good lighting would add only 15 minutes time per day to the output, it would readily pay for itself and show a substantial profit in addition.

SPOILAGE

In addition to the question of accidents and increased production, the factor of spoilage enters largely into the question of industrial lighting.

Data has been published in the United States Census report for 1909, which shows the gross spoilage in the American factories $150,000,000 per year, of which amount $28,125,000 is due to poor artificial lighting and could be avoided by an improved lighting method.

Good lighting results in a decrease of flawed products marketed as perfect goods and it also cuts down the need for inspection by increasing the precision of each workman and operator. One manufacturing company reported that the proportion of its products which had to be sold as seconds were reduced nearly 40% after the lighting had been improved.

Up to a few years ago when very little attention had been given to the lighting of cotton goods mills, summer made goods usually sold for a higher price than those made in the winter months, for the reason that the goods manufactured in the summer were made

under daylight conditions and were, therefore, of better quality. The greater percentage of these mills now have modern lighting systems and the winter made goods show a marked improvement.

Data taken by the National Electric Light Association from various manufacturers indicate that of 209 who recently installed up-to-date factory lighting, 164 believed that quantity and quality of production had increased. 31 of the manufacturers specifically stated that their goods were better made than previously and that spoilage and seconds had decreased.

In addition to the factors already discussed, come the question of welfare of employes, and the attendant psychological effects.

Manufacturers are paying more attention to employes comfort. They are providing ventilation together with clean well lighted work rooms, not only from a humanitarian

standpoint, but because they actually pay dividends in more and better work turned out. Men who are working in a more or less discontented drowsy fashion are unconsciously speeded up and become more cheerful and healthy.

Continued irration of the various nerves of the eye, has a very depressing effect on the entire body and will finally result in slowness and inaccuracy.

After a consideration of the foregoing factors which indicate the necessity for good artificial lighting, the requirements for good lighting may be discussed.

REQUIREMENTS FOR GOOD LIGHTING

The requirements for good artificial lighting may be conveniently sub-divided under four headings.

1. Sufficient light of proper quality on the work.

2. Absence of "glare".

3. A moderate intensity of light over the area adjacent to the work and on the walls.

4. A system which is simple, reliable and easy to maintain as well as comparatively low in operating cost.

AMOUNT AND QUALITY OF LIGHT

In considering the first and most important requirement, that of providing sufficient light of proper quality on the work, it may readily be seen that if we are to view the subject from an economic standpoint there are many factors involved. The intensity will depend on the cost of producing light, the wages of the employes, the value of their output, the nature and fineness of their work, and the possible reduction in spoilage. From time to time there have been many figures published covering estimates of the intensity of illumination required for any class of work but these have been, of necessity, based on other than purely

economic considerations.

The minimum permissible intensity of light in a factory is determined by the question of accidents. Most authorities have agreed that .25 of a foot candle should be taken as a lowest possible limit. However, the upper limit may run anywhere from 50 to 100 foot candles. These higher intensities of illumination are required for operations involving fine details, rapidly moving machinery and black surfaces. The shoe industry particularly requires high intensities. In discussing the question of required intensities with the manufacturer, the question is often asked, "If I double this lighting intensity to what extent is my vision aided and again up to what limit is it of value to continue to increase the lighting intensity?"

Investigation has shown that after the apparent brightness of an object has

reached a certain magnitude, a further increase in intensity does not appreciably aid vision. The necessary volume of incident light is dependent upon the "Coefficient of Reflection" of the object illuminated. For instance - dark goods reflects less light than light goods so it is usually necessary to have much higher intensities when working on dark goods than when working on light goods.

In those places where intensities of 50 to 100 foot candles are required, special arrangements are usually made to take care of the situation by a local light as these high intensities by general illumination are, under the present conditions, not economical.

The various tables published by the Engineering Societies, giving definite recommendations as to the amount of light required for various kinds of work, should be used spar-

ingly and only in connection with knowledge gained from past experience.

The writer's experience in the past four years in industrial lighting work, has led him to adopt as a basis for figuring the following intensities.

	Foot candles
Wood and sheet metal working Foundry and Forge shops	2. to 3.5
Machine shops, cabinet making, assembling, erecting	3.5 to 7.

It is impossible to say definitely just what intensity is most suitable for any particular class of work, so that the tables given above must necessarily cover a comparatively wide range and each problem must be treated individually when the engineer has a knowledge of conditions. As stated previously, the cost of operating a lighting system is a small percentage of the compensation paid to the workmen and at the same time is of great importance. The engineer of today is, therefore, continually figuring higher and

higher intensities for factory lighting and will continue to do so, until the time comes when such intensities will be in use that there will be no question any time during the life of the installation as to the adequacy of the illumination.

Diffusion

If a sufficient intensity of light is to be provided at all times on the work, consideration must be given to the question of diffusion. Particularly in the cases of over-head lighting systems, it is necessary to arrange the units so that light comes from three or four directions on the bench. In this way, if light is cut off from one or two directions by the operator, there is always light on the work. In the event that any one of the lighting units is temporarily put out of service, the workman is not greatly hindered.

If the installation is made up of a comparatively small number of large units,

particularly of the new Mazda C gas-filled lamps, shadows are likely to be very much pronounced and there is a decided decrease in the illumination when one unit is extinguished.

Distribution

The uniform distribution of the light is also important. In designing industrial lighting equipment, care is always taken to produce units which will give as uniform a spread of the light as possible. This problem may be partially solved by using a larger number of small units to cover a given area. The spacing and mounting height of industrial lighting units is determined solely by the uniformity of distribution required while the intensity determines the size of the unit. The usual spacing in factories today runs from one and a half times to two times the height above the working plane.

Steadiness

Steadiness of illumination is being more and more emphasized by illuminating engineers when making recommendations for industrial lighting. A varying intensity on the work may be caused by fluctuation in voltage which effects the output of the light source, by moving objects which cause shadows and by moving sources.

The effect of a flickering light will be readily understood by any one who has ever left a dark room and passed into the bright sunshine. The sensation is particularly unpleasant, but nevertheless a flickering light produces this sensation many times a minute. The eye attempts to adjust itself in such a fashion as to keep the intensity on the retina almost constant. This means that the iris of the eye is opening and shutting many times a minute and the muscle which governs it gets very tired, causing a re-action on the

nerves and intense pain eventually results.

In the writer's experience the trouble due to flicker has usually been caused by varying voltage on the line, which in most instances is due to the fact that heavy power loads are connected on the same circuits as the lighting.

When these heavy loads are thrown on and off, the drop in the line voltage varies and the output of the lamp varies with it but in much greater proportion.

It is, therefore, often the task of the illuminating engineer to bring about a complete re-arrangement of the power and lighting circuits in order to secure a steady light source.

Color

The question of color quality in industrial lighting is being given continually increased attention. In some manufacturing processes color distinctions are absolutely

necessary and in many plants the introduction of the Mazda C2 daylight lamp has been welcome.

In this lamp the flux of the ordinary incandescent filament is filtered by means of a special blue glass bulb so that the resulting output has about the same quality light as daylight.

These lamps or similar arrangements are being used by dye makers, lithographers, tailoring shops, etc.

In smoky atmospheres, such as are sometimes encountered in foundries, it may be advisable to use flame arc lamps which give yellow rays as these rays seem to have the property of penetration.

On a smoky or foggy day the sun usually appears a deep red, which indicates that it is only the longer wave lengths of light that will penetrate the dense atmosphere. However, this should not be taken to mean that

any lighting unit giving a yellow light is preferable for use under smoky conditions, as the original efficiency in lumens output per watt together with maintenance cost must be given careful consideration in selecting the lighting unit.

GLARE

Glare, which is sometimes defined as "light out of place", has come to be regarded as one of the most importance factors contributing to "make or break" the lighting system. The term, glare, is usually meant to cover both ocular discomfort and eye strain.

The eye can only do its work when it is allowed to adjust itself for the intensities on the object which it is viewing and if it is affected by a number of other sources, it is unable to perform its task efficiently. Under conditions of well diffused lighting, where the light source is screened from the

range of vision, 4 foot candles may be very satisfactory for performing a given task, but if a bare light source is suddenly brought into the range of vision, the eye is blinded and 10 foot candles of illumination might not prove adequate to enable the eye to work efficiently.

Glare need not necessarily be caused by a light unit, it may be merely a brightly illuminated surface not far from the line of vision or even some polished portion of the work itself in which the image of the light source becomes apparent.

Investigations have been made bearing on the extent to which the vision is, for the time, impaired by glare;and indicate that this effect depends primarily on the total quantity of light received by the eye directly from the source rather than upon the intrinsic brilliancy. Therefore, the distance between the eye and the source is of importance. For

a given light source, the further they eye is from it, the shorter time the discomfort caused by the glaring unit is likely to last.

In the case of the source of the lower intrinsic brilliancy, that is, where the candle power per unit of area is low, the effect of glare usually disappears very soon after the cause is removed. However, if the source is one of high intrinsic brilliancy, such as the filament of a Mazda lamp or the crater of an arc, it may not only decrease the ability to see during its presence within the field of vision, but will also tire or permanently injure the eye.

In designing a lighting system, it is, therefore, essential that extreme care be taken to see that all light sources are properly screened from the range of vision and that polished surfaces are avoided to as great an extent as possible.

Where it is impossible to screen the

source of light entirely, the presence of a brightly lighted background, such as the surface of a reflector, will considerably diminish the harmful effect which is to a certain extent due to contrast.

If the eye is to be allowed to focus itself accurately on the work, very little light should be allowed to enter it from any other source. In addition, the intensity on objects within the field of vision when the eye is focused on the work, should be very close to that of the intensity on the work.

LIGHT ON ADJACENT AREAS

In considering the amount of light there should be on areas adjacent to the work and on the walls, the subject of the "General" versus the "Localized" system, immediately comes up for consideration.

The present tendencies in the industrial lighting field seem to indicate that

the system of general lighting is the one which has come to stay.

A local system of lighting is one in which high intensities of light are produced, on the spot where the work is done, by means of drop cords or portable lamps.

A general system is one in which the lighting is accomplished by a number of light sources hung fairly high and spaced at uniform distances, thus producing approximately the same intensity of light throughout the entire room together with a moderate intensity on the wall.

In many of the shops which are lighted by local systems, the intensity in the aisles is so low that one can scarcely see his way about. This kind of lighting is not only inadequate, from the standpoint of safety, but also strains the eye. If the work is brilliantly lighted and the rest of the room is in comparative darkness, the un-

even intensity encountered by the eye in shifting from the work has a tiring effect not unlike that of a flickering light source.

A system of general lighting has a tremendous psychological effect on employes. Instead of having a dark dingy shop with bright lights in spots, the entire room is filled with illumination and has a most cheerful effect. Shadows are eliminated and the workman may perform his task at any point without reference to the lighting system.

No time is wasted in the adjusting of drop cords or bracket lights. The system can be kept up-to-date at all times by putting in a regular maintenance system and the depreciation on the lighting units themselves is practically nothing while in the case of brackets which are used for local lighting, the depreciation is high, due to the rough handling by various men.

Strictly general lighting can be applied to most any shop interior, but occasionally it is necessary to modify it somewhat to the type of lighting which is known as "localized general". In this case a lighting unit is selected which is suitable for the average condition and the outlets are then located in reference to various operations, so there will be no shadow on the work. At the same time, the fact that these units are hung up high, means that they will spread considerable light into adjacent areas and, therefore, make the entire place well lighted.

Much difficulty has been experienced in attempting to mix artificial with natural light.

Experiments were conducted about a year ago on a factory employing about 500 men, to determine the amount of work which the men would do under artificial light-

ing when mixed with daylight.

In making the tests it was found that the work fell off rapidly as the natural light decreased. With the addition of artificial light on a particularly dark day, the work increased. However, on a brighter day when the artificial light was added the work decreased. This seems to show that the addition of artificial light to a low intensity of daylight decreases the efficiency of a working force and it would probably be better to exclude the daylight entirely when it becomes necessary to turn on the artificial system.

In the writer's experience it has been found that when natural lighting is received from the West, particularly in the late afternoon, artificial systems giving intensities up to 10 foot candles are almost ineffective. However, if shades are drawn and the natural lighting cut off, the artificial system

serves the purpose in a most satisfactory manner.

In the lighting of plants where the artificial system must be used in confliction with the daylight system during a portion of the day, consideration should be given to the question of putting in higher intensities so that the artificial system may be a factor in comparison with the daylight.

AVAILABLE INCANDESCENT UNITS

During the last two years there have been tremendous developments and advancements in the manufacture of incandescent units.

The most noteworthy of these developments has been that of the Mazda "C" gas-filled tungsten lamp, sometimes called the "Nitrogen" or "Half-Watt" lamp.

The old Mazda "B" or vacuum type tungsten lamp had a filament of drawn wire

which was looped back and forth over a hanger and occupied considerable space in the bulb. The Mazda "C" lamp has a coiled or concentrated filament which is surrounded by an inert gas, such as nitrogen or argon, which when the lamp is under operating conditions comes up to a pressure of approximately one atmosphere. By the introduction of this gas in the bulb, it is possible to operate the filament at higher temperatures, thereby, securing far greater efficiency in lumens output per watt input.

Where the old Mazda "B" lamp was operated at an efficiency from 7.5 to 10 lumens per watt, the new Mazda "C" lamps are operated at 11.5 to 18 lumens per watt. This is an increase of from 25 to 90% according to the size of lamp.

The latest schedules, as issued under date of May 1st, 1917, are shown on the following page:

Lamp Price Schedule T-1
Mazda Class-Large Style-Straight Side and
Pear-Shape Types

Size Lamp Watts	Lumens per Watt	Watts per S.P.C.	Type Size Bulb	Base Reg. Sup.	List Price Cl.	List Price Fr.
110 to 125-volt straight side (Mazda B)						
10	7.52	1.67)	S-17	Med.	$0.27	$0.30
15	8.55	1.47)				
25	9.04	1.39)	S-19	Med.	.27	.30
40	9.31	1.35)				
50	9.45	1.33	S-19	Med.	.27	.30
60	9.59	1.31	S-21	Med.	.36	.40
100	9.97	1.26	S-30	Med.	.65	.72
110 to 125-volt Pear-Shape (Mazda C)						
75	11.53	1.09	PS-22	Med.	.65	.70
100	12.57	1.00	PS-25	Med.	1.00	1.05
150	13.66	0.92	PS-25	Med.	1.50	1.55
200	14.61	0.86	PS-30	Med.	2.00	2.07
300	16.11	0.78	PS-35	Mog.	3.00	3.10
400	15.32	0.82	PS-40	Mog.	4.00	4.15
500	16.11	0.78	PS-40	Mog.	4.50	4.65
750	16.98	0.74	PS-52	Mog.	6.00	6.25
1000	17.95	0.70	PS-52	Mog.	7.00	7.25
220 to 250-volt straight side (Mazda B)						
25	7.62	1.65	S-19	Med.	.33	.36
40	8.27	1.52	S-19	Med.	.33	.36
60	8.61	1.46	S-21	Med.	.45	.49
100	9.04	1.39	S-30	Med.	.80	.87
150	9.45	1.33	S-35	Med.	1.20	1.30
250	10.47	1.20	S-40	Med.	2.00	2.15
220 to 250-volt Pear-Shape (Mazda C)						
200	12.57	1.00	PS-30	Med.	2.20	2.27
300	13.66	0.92	PS-35	Mog.	3.60	3.70
400	13.96	0.90	PS-40	Mog.	4.80	4.95
500	14.78	0.85	PS-40	Mog.	5.40	5.55
750	15.32	0.82	PS-52	Mog.	7.20	7.45
1000	16.11	0.78	PS-52	Mog.	8.40	8.65

In observing these tables it is interesting to note that for the first time the figures have been published on the regular data sheet giving lumens per watt.

The old method of rating lamps was on the watt per horizontal candle power basis. This was particularly unsatisfactory due to the fact that the reduction factors of the new Mazda "C" lamp are different than those of the old Mazda "B" lamp. The only basis, therefore, on which the two lamps could be compared was on the watt per mean spherical candle power basis. This method is also unsatisfactory for rating, because most calculations are now being made by the "flux method" instead of by the old "point by point" method. Consequently the illuminating engineer is interested in knowing how many lumens output any particular source gives.

The Illuminating Engineering Society and the Lamp Works have, therefore, been con-

ducting an educational campaign during the last year to educate the public to a knowledge of what a lumen is; and in the near future incandescent lamps will probably be spoken of as a "1200 lumen " lamp or a "1600 lumen" lamp, instead of a "100 candle power" or "125 candle power" lamp.

In selecting incandescent lighting units, the question often comes up as to what voltage should be used, that is 110 or 220. It may readily be seen from the tables that the cost of the 220 volt lamps is higher and the efficiency lower. Also due to the longer and thinner filament they do not possess the ability to withstand as rough usage as do the 110-volt lamps.

Where a source of 110 volts is not available, it is possible to arrange to use 110-volt lamps by installing a balancer coil of low capacity and arranging the incandescent circuit so that it will be well balanced.

As a general rule it is not desirable to burn two 110-volt lamps in series on a 220-volt circuit unless the lamps are especially selected at the factory for series burning.

When lamps are ordered in this manner they are carefully selected to have the same resistance and, therefore, give good results. However, if they are not so selected, one lamp may burn slightly brighter than the other and during the life of the lamp this difference grows greater and greater until a burn-out occurs.

METHOD OF CALCULATION

The two methods in most common use for calculating of lighting intensities are those known as the "point by point" and the "flux" methods.

The point by point method is a very slow and tiresome way of calculating lighting. By this method the illumination at

any particular point is determined by dividing the candle power in the direction of the point by the square of the distance from the light source to the point and then making a correction by means of the Cosine law for the angle of the incident light.

This method is often found useful in calculating yard lighting where it is desirable to illuminate some particular object at a distance from the lighting unit such as an angle reflector or a bowl type unit mounted high in the air. However, it is not suitable for interior calculations as it is too lengthy.

The "flux" method of calculation is the one which is used to the greatest extent in calculating and laying out lighting systems and is based on the efficiency of utilization as determined by previous tests and experiments.

The efficiency of utilization of a lighting system is the ratio of the total

flux in lumens received on the working plane, to the lumens generated in the lamp. When this ratio expressed as a percentage has been determined for the different possible arrangements of several types of reflectors on the market, the foot-candle intensity resulting from any particular installation may be quickly determined by multiplying the generated lumens per square foot by the utilization efficiency expressed in the percentage. The formula is given below:

Let L = the total lumens per lamp
K = the utilization efficiency
A = the average number of square feet to be illuminated by each lamp
I = the average intensity in foot candles

$$I = \frac{L \times K}{A}$$

A number of different figures have been published by various authors and the writer has during the last four years made a number of tests on various installations. As a result of these tests and previous figures

he has arrived at an empirical table which can usually be depended on to give results within 5 or 10% of the actual figures as would be determined by a photometric test.

For a rapid and suitable method of calculating illumination, the following data have been prepared:

The "lumen" is the unit of light output and is defined as the amount of light radiated in a unit solid angle from a uniformly distributing source of one spherical candle-power. As there are 12.57 such angles around a point, there must be 12.57 lumens from one candle-power.

The foot candle is the unit of light intensity and is the amount of illumination received on a spherical surface one foot from a source of one candle-power.

From the foregoing definition it is apparent that the concentration of one lumen on a square foot of surface will give an intensi-

ty of one foot-candle. If two lumens are distributed over a square foot of space, the intensity will be two foot-candles, etc., etc.

From experience in lighting various types of buildings, a table of "Recommended Intensities" has been compiled. This forms a basis for properly calculating and laying out of a lighting system.

Recommended Intensities
(Table No. 1)

Wood and Sheet Metal Working, Foundry, Forge Shops, 2.0 - 3.5.

Machine Shops, Cabinet Making, Assembling, Erecting, 3.5 - 7.0.

After selecting the desired intensity for the particular class of service, the total number of required lumens may be obtained by multiplying the intensity by the number of square feet in the area to be lighted and dividing this figure by the utilization factor as given in the table below:

Utilization Efficiencies
(Table No. 2)

Arrangement of Units	Reflector: Skirted Cone or Shallow Bowl	Deep Bowl Type
1 Row of Units	43	36
2 Rows of Units	48	41
3 Rows of Units	56	47
6 Rows of Units	63	51
8 Rows or more	67	54

Figures based on light ceilings and medium walls.

For rooms with dark ceilings and walls reduce results 8 per cent.

After this the number and type of units and spacing distance should be determined from the data below.

Spacing
(Table No. 3)

Skirted Cone - 1.7 to 2.3 times the height above working plane.

Deep Bowl - 1.2 to 1.9 times the height above working plane.

Dividing the total lumens by the number of units gives the lumens required

per lamp.

The proper lamp rating in watts may be determined by referring to the following table and selecting the lamp which gives the nearest output in lumens to the numerical amount which has, from calculation, been found to be required.

Output of Lamps in Lumens
(Table No. 4)

Lamp Rating Watts	105-125 Volt Mazda C Lamps Lumens	210-250 Volt Mazda C Lamps Lumens
75	865	. . .
100	1260	. . .
200	2800	2520
300	4600	4100
400	6150	5600
500	8050	7400
750	12800	11500
1000	18000	16100

Example

Assume the problem of lighting a machine shop. Dimensions as given below.

Width	=	45 feet
Length	=	105 feet
Ceiling	=	12 feet
Bays	=	15 feet square
Voltage of Supply	=	110

Recommended intensity (From table No. 1)	=	6 foot candles
Area	=	45x105 = 4,725
Utilization factor (From table No. 2)	=	56%
Required lumens	=	(Area-4,725) times (Intensity-6) divided by utilization factor-.56 = 50,625.

Assume one unit per bay, which means a spacing distance of 15 feet. Consult Table No. 3 on Skirted Cone Type, and assume a factor of 2.0.

Hanging height	=	15 divided by 2 = 7 1/2 ft.
Working Plane	=	3 1/2 ft.
Height of unit above floor	=	3 1/2 plus 7 1/2 = 11 ft.
Number of units	=	21 (1 unit per bay)
Lumens require per unit	=	50,625 divided by 21 = 2,411

Refer to table No. 4 and select lamp showing the closestlumen rating to 2,411.

Lamp selected is 200-watt Mazda "C".

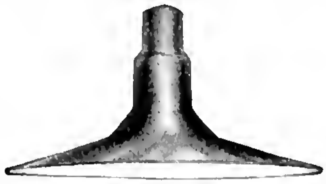
Reflector No. 8540 Maxolite. Skirted Cone Type.

MANUFACTURE OF STEEL REFLECTORS

In addition to having a knowledge of the laws of light and the requirements of industrial lighting, the illuminating engineer must also have a knowledge of the operations entering into the manufacture of steel reflectors before he can design a line which will be practical and marketable.

The present tendencies in industrial lighting are toward the adoption of the one piece enameled steel reflector which is made with a long neck to enclose the socket, so the writer is confining himself to the manufacture and design of this type of unit. The general appearance of these reflectors is shown by figure 3.

The reflectors, with the exception of the extremely large sizes, are generally drawn from #22 gauge steel which is worked cold. The process of spinning is sometimes employed for the shaping of the steel but with this method the metal is stretched to a considerable extent



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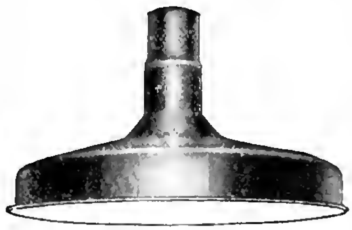

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Figure 3

and, therefore, becomes thin in places. When the work is done by drawing through reducing and finishing dyes, the thickness of the metal is kept almost uniform and a much more serviceable reflector results.

The steel comes from the mills cut in square sheets of a definite size which are known as "blanks".

The first step is to put the sheet in a lathe and cut it into circular form of the required size. It is then worked step by step through a set of reducing dyes, being drawn into the shape as shown approximately in figure 4.

After it is drawn into approximate shape by the reducing dyes, it is put into a set of finishing dyes, such as illustrated in figure 5, and brought to a shape more nearly resembling the finished product.

When it emerges from the finishing dyes, the steel shell has a number of wrinkles in it, so that it is necessary to put it on a

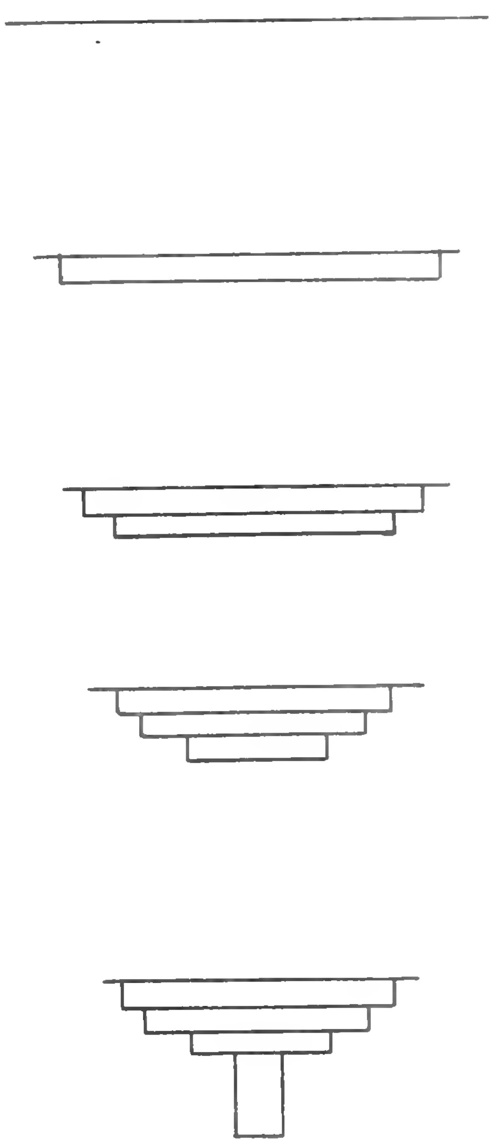


Figure 4

FINISHING DIES

A - Blank Holder

B - Punch

C - Socket

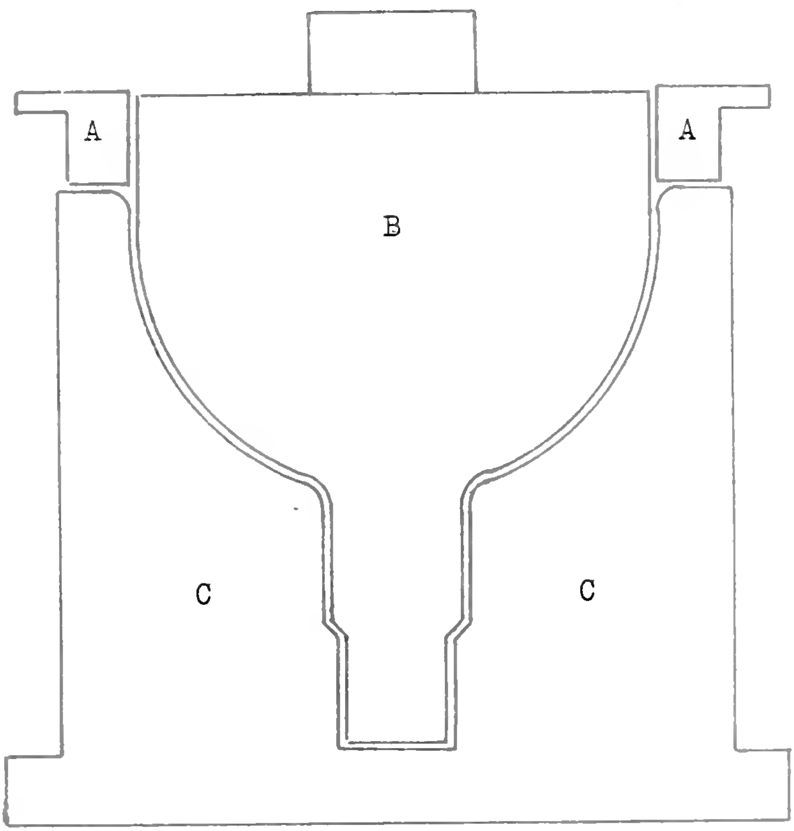


Figure 5

spinning chuck, shaped practically the same as the punch in the finishing dye, and smooth it out.

After being straightened out on the spinning chuck, the edges are trimmed off and a bead is spun at the bottom of the reflector. It is possible to smoothly enamel the bead and thus make the steel inaccessible to moisture at that point.

After this process, the shells are ready to be enameled and they are first dipped in a solution of hydrochloric acid and then annealed by being brought to a temperature of about 1400° Fahrenheit, and upon cooling all the scale and impurities on the metal are easily removed.

The pickling or cleaning process is next. The steel shells are dipped in hydrochloric acid and then washed off in two successive tanks of warm watter after which they are boiled in soda. They are then placed on steam

pipes and allowed to dry thoroughly.

After drying the first or filler coat of enamel is put on by dipping the reflector in enamel, drying it at 150°, and then burning it at about 1750° Fahrenheit.

After being allowed to cool, the first coat of white enamel is sprayed on the inside and the blue or finishing coat is sprayed on the outside. The reflectors are then dried at 150° and again burned at about 1600° Fahrenheit.

They are then allowed to cool, an extra coat of white enamel is sprayed on the interior and a black enamel is put on the edge of the bead by hand. The reflectors are then allowed to dry at 150° and once more burned at 1600° Fahrenheit. When they emerge for the third time from the furnace, the finish is absolutely smooth on the interior and exterior and a very efficient white surface results on the interior.

When observing the process of drawing, it may readily be seen that the fewer right angles there are on the finished product, the easier will be the manufacture and the smaller amount will be the spoilage.

Straight draws of a constant diameter should be avoided as far as possible. When designing the neck of the reflector, several steps are usually inserted so that the length of the neck may be secured by gradually reducing the diameter step by step, thus giving a tapering effect and avoiding tearing the metal.

If reflectors at a low cost are to be secured, the shape must be so as to require the least amount of metal. The deeper the reflector, the more metal is required. However, an inch of extra depth in the neck of the reflector will not take as much metal as one extra inch of depth in the bowl part, where the diameter is large.

THE DESIGN OF INDUSTRIAL LIGHTING UNITS

Up to the time of the introduction of the Mazda "C" lamp, about two years ago, there were four general types of reflectors on the market, that is: the flat cone, shallow bowl, deep bowl and angle type.

When the Mazda "C" lamps were placed on the market, the centers of the filaments of these lamps were placed in approximately the same position as those of the Mazda "B" lamps of the same wattage and it was, therefore, assumed that the new lamps could be used in the same reflectors as had been used with the Mazda "B" lamps.

The shallow bowl type had been used to the greatest extent, due to the fact that it protected the eye better than the flat cone and being larger in diameter than the deep bowl, had a lower apparent brightness and also caused less prominent shadows.

An installation was made of 200-watt

Mazda "C" lamps in 16" shallow bowl reflectors, which had been previously used with the old Mazda "B" lamps. It was particularly noticeable that the light between the units was far less than that directly beneath them and a survey was accordingly run between two units, 14 feet apart and mounted 8 feet above the working plane. The results of the survey indicated that there was a decided lack of illumination between the units although there was a "peak" directly beneath the fixtures.

The reflector was immediately sent to the testing laboratory and a curve, such as is shown under the shallow bowl type reflector in figure 6, was secured.

The concentration of the light below the reflector was apparently due to the specularly reflected light, so that it could be immediately seen that there was a necessity for a complete re-design of the unit for use with the Mazda "C" lamp.

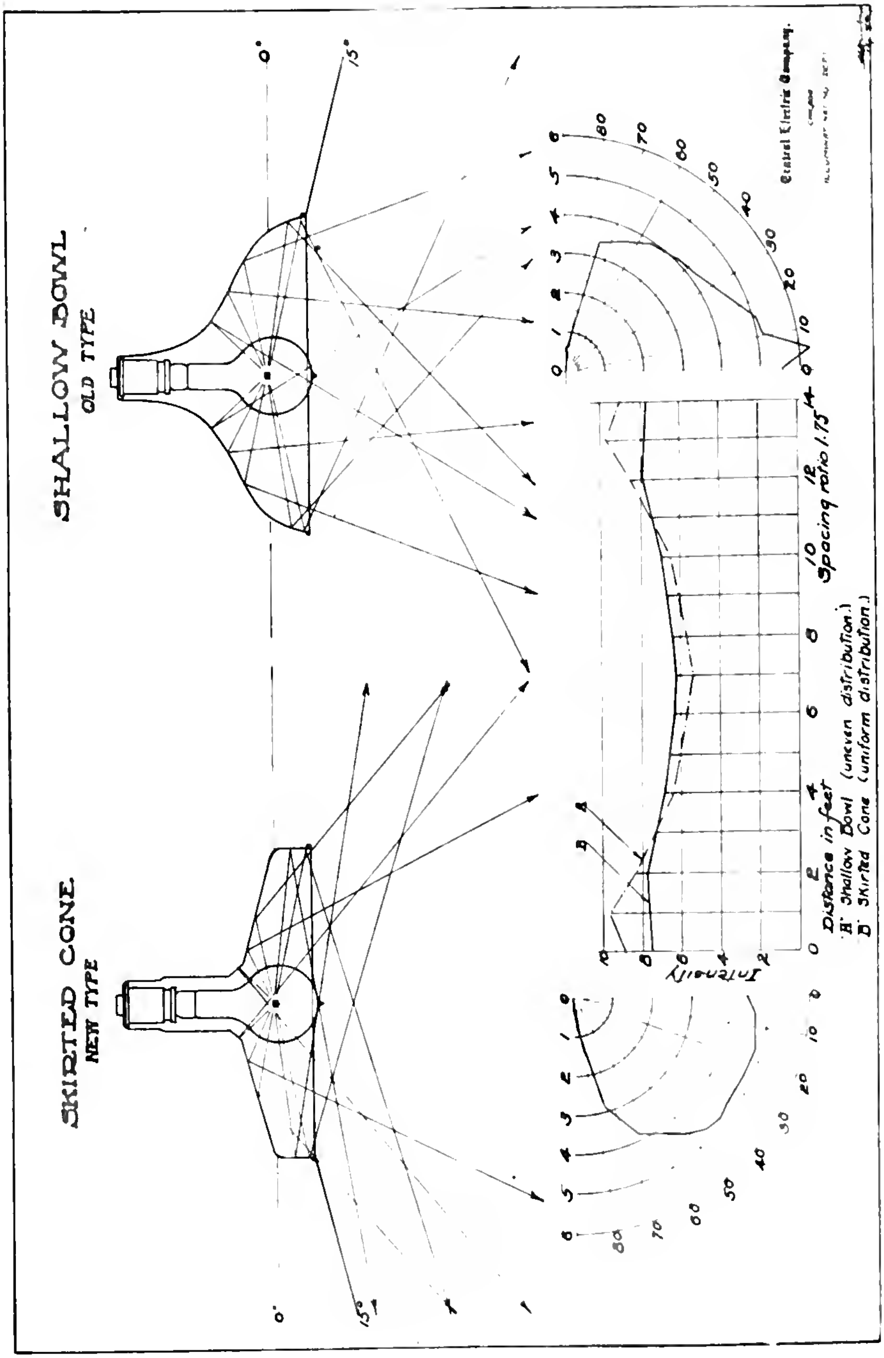
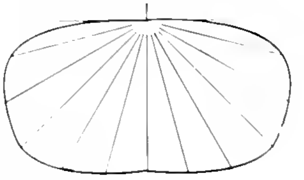

SHALLOW BOWL
OLD TYPE
SKIRTED CONE
NEW TYPE
Distance in feet
Spacing ratio 1.75
Intensity
'A' Shallow Bowl (uneven distribution.)
'B' Skirted Cone (uniform distribution.)
General Electric Company.

Figure 6

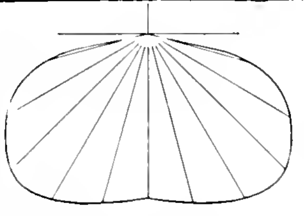
After a careful consideration of the requirements of the railroad companies and the industrial plants, it was decided that three types would be placed on the market, namely: the flat cone, shallow bowl and deep bowl types.

It was decided that the flat cone reflectors should be the one that would meet the requirements for the widest possible spread of illumination. As there was no necessity for wasting the light in an upward direction, the center of the filament of the Mazda "C" lamp was placed in direct line with the lower edge of the reflector and the reflector itself was made as flat as possible.

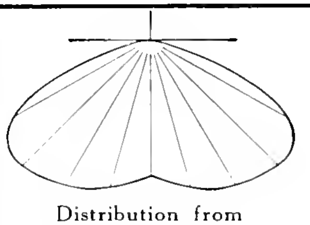
A cut-off of 15° below the horizontal was decided upon for the shallow bowl reflector, as it was found that for the general condition of spacing on centers of 12 to 20 feet with ordinary hanging height, no glare was experienced and all filaments were properly shielded with a possible exception of that of the closest unit to the ob-



Distribution from Flat Cone Reflectors



Distribution from Skirted Cone Reflectors



Distribution from Deep Bowl Reflectors

server.

For bench lighting and for use on high ceilings, where downward concentration of light is required, the deep bowl reflector with its cut off of 25° was standardized.

The diagram in figure 7 shows in a very clear way the manner in which the various reflectors enclose the lamp. It has been found that this diagram, when submitted in connection with a catalogue, means a great deal more to the manufacturer or layman who is attempting to fix up his own lighting equipment, than does a complete set of distribution curves showing the candle power in various directions.

In the actual designing of the reflector, the first step is the selection of the porcelain socket and fitting by which it is fastened to the reflector and from which the entire unit is suspended.

Figure 8 shows the porcelain socket

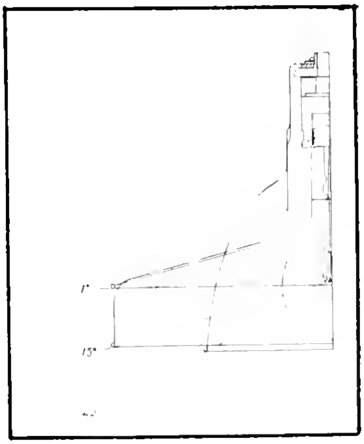
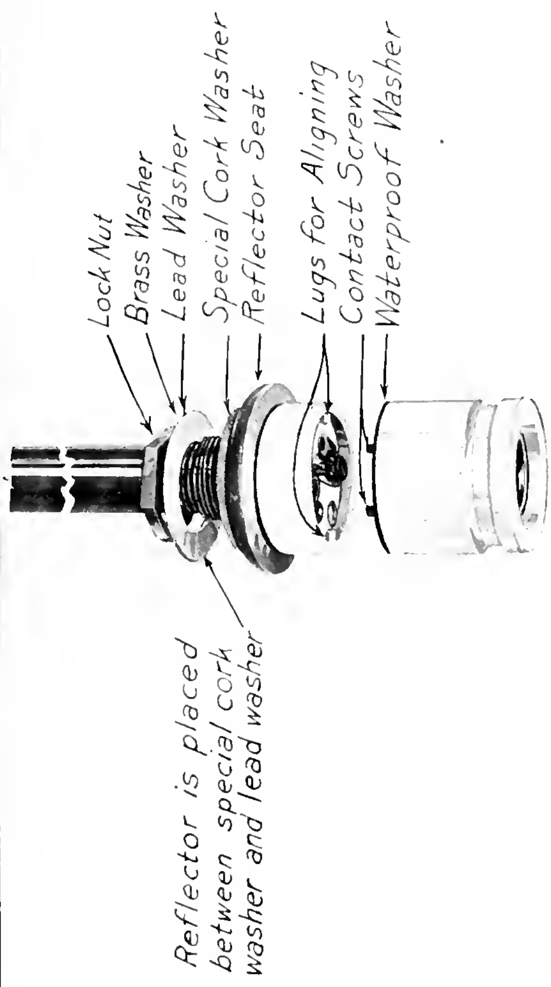


Figure 7



(Patented)

Details of Type "R" Maxolite Fitting

Figure 8

and malleable iron fitting with washer, which was chosen for use with the reflector. This fitting had been previously in use with the old type of unit and was found suitable under the most severe condition.

In choosing the fitting, care must be taken to protect the raw edge at the top of the reflector from moisture, as corrosion once started will carry throughout the reflector causing the porcelain enamel to scale off entirely. With the fitting which was selected, the reflector is held between a cushion forming cork washer beneath and a heavy lead washer above. The lead washer prevents moisture from reaching the edge of the reflector and at the same time is proof against attack by acid fumes. The cork washer prevents chipping of the reflector beneath, due to the tightening of the lock-nut.

The fitting itself is made of malleable iron and screws directly to the conduit, carrying the entire strain due to the weight of the re-

flector. In outdoor work it takes up the stresses due to wind pressure on the reflector.

The arrangement of lock-nut, washer, fitting and socket is such that the units may be easily taken apart and wired. A spring lamp grip is furnished in the socket to prevent the lamp from turning out and causing heating due to poor contact as well as possible damage or injury due to falling glass from the bulb of the lamp.

After laying out in section the fitting and socket the lamp with its filament is drawn into position.

The next step is to decide upon the angle of cut off in relation to the horizontal, in other words, the angle of eye protection, and after that to shape the reflector so as to secure the desired distribution.

As stated previously, the flat cone reflector was arranged so that the filament should be in line with the lower edge of the unit. A

slant of 15° with the horizontal for the main part of the reflector was decided upon as this was the minimum slope which could be given without the reflector warping when heated to high temperatures in the furnace. Due to the open nature of the reflector, ventilation was found unnecessary on sizes of 200-watts and under. However, on the reflectors for 300 to 1000-watts, ventilation holes around the neck of the reflector were required.

The diameters of the reflectors were chosen somewhat arbitrarily to meet existing competitive conditions in the market, no special tests being made, since these diameters had been satisfactory on previous installations.

The following diameters were selected:

25-75-watt	12 inch diameter
100, 150-watt	14 inch diameter
200, 250-watt	16 inch diameter
300, 400, 500-watt	18 inch diameter

It will be noted that the 100 and 150-watt Mazda "C" lamps were included in the same reflector as the distance from the filament to the

base is the same in both lamps.

This is also true of the 200 and 250-watt lamps as well as the 300, 400 and 500-watt lamps.

The design of the shallow bowl or what was finally termed the "skirted cone type" was the most difficult.

By referring again to figure 6, a section of the old shallow bowl reflector designed for Mazda "B" lamps and one of the new designs of the reflector known as the skirted cone for use with the Mazda "C" lamps may be seen.

When the shallow bowl was used with the Mazda "B" lamp it gave a distributing type of curve with very uniform illumination for some distance from the reflector. However, when this same reflector was equipped with a Mazda "C" lamp, its peculiar shape seemed to have a focusing effect and the greater part of the specularly reflected light was directed downwards beneath

the fixture, the resulting curve being shown in the diagram. The general direction of the specularly reflected light is also shown and it will be seen that most of the light is reflected downwards.

The skirted cone type is similar to the flat cone, but has a straight edge which serves the double purpose of throwing the light into the 30 to 60° zone and at the same time protecting the eyes of those working under the light. This unit gives a curve as shown at the right of figure 6 resembling the distributing type of the old Mazda "B" lamp in the old reflector. However, it gives much more uniform results, as is shown by the diagram in the center.

The solid line indicates the result of a linear survey between two skirted cone units with 200-watt Mazda "C" lamps, hung 14 feet apart and 8 feet above the working plane. The variation of light intensity from

highest to lowest is about 16%. The dot and dash line indicates a survey between two of the old shallow bowl reflectors equipped with the same 200-watt Mazda "C" lamps hung the same distance apart and the same height above the working plane.

The variation in intensities for the old type units is about 100% from high to low point, which is far greater than that with the skirted cone unit.

The overall efficiency of lighting output in lumens of the skirted cone units is about 3% better than that of the shallow bowl, the light distribution being more uniform and the eye protection being sufficient for ordinary factory installations. The designing of enameled steel reflectors for use with Mazda "C" lamps is hardly an exact or mathematical procedure.

It was necessary to make up a number of shapes from wooden chucks, for trial purposes, until the correct distribution was finally secured.

There would be no difficulty in getting a wide type of distribution if it were not for the fact that it was necessary to bring the reflector down well around the lamp in order to protect the eye.

The act of bringing the reflector down around the lamp increased the concentrating effect of the reflector and it was only after a considerable trial that the desired results were secured.

The diameters selected for the skirted cone type units are the same as those for the flat cone type.

Deep Bowl Units

The designing of a deep bowl reflector was not found so difficult as that of the skirted cone type. After selecting the diameter, an angle of cut off of 25° was laid out.

When the trial reflectors were made up, distribution curves of the well known exten-

sive type were secured and as they were quite satisfactory, the manufacturing was immediately started.

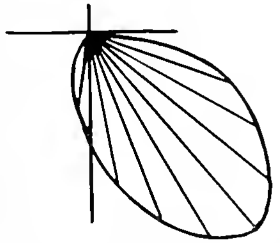
Angle Units

Angle type reflectors were designed for lighting of bill boards, show windows, narrow high places which could not be economically lighted from above, and spaces where the overhead was obstructed by construction work, moving cranes or other machinery.

It was decided to make a reflector that would confine practically all of the light within the useful 90° angle and throw the high candle powers in the 30 to 60° angle, thus producing a very uniform light on both horizontal and vertical planes.

As these reflectors are hung fairly low, the filament was set back well into the reflector in order to prevent direct glare from it when observing the reflector from the side.

It was impossible to make the angle



Distribution Curve

No. 9723

reflector of one piece of drawn steel due to the fact that it was not symmetrical. The neck was, therefore, made in one piece and the bowl drawn separately. The two were then spun together and enameled in one piece.

When care is taken in the manufacture, the seam between the two pieces may be made absolutely weather-proof and there is no danger of depreciation.

After the reflectors had all been designed, competitive bids were taken on the manufacture of the drawing, dyes and reflectors.

After the letting of these contracts, close cooperation was given to the Publicity Department and a complete catalogue was prepared, giving all data which might be required by any one who would consider the purchase of reflectors.

On each page the catalogue number, description of the reflector, diameter, overall depth, size of socket and list price were given.

In addition to thesedata, sectional

drawings of the reflectors were shown, so that the position of the filament in relation to the edge of the reflector might be readily seen.

The complete line has been on the market for nearly a year and about 40,000 units are now in use.

Conclusion.

In surveying the present tendencies in the industrial lighting field, it appears that there is a desire, if possible, to reduce the effects of glare and at the same time to promote the use of higher intensities.

In designing the equipment described in the foregoing, it has always been the writer's desire to make the reflectors as deep as possible so that protection to the eye might be given. It must be remembered, however, that the deeper the reflector, the less the light output and, therefore, until the public is educated to the fact that glare is a bigger factor than the actual light

output in determing the usefulness of a unit, the depth of the reflector must be somewhat limited.

Wherever possible, bowl frosted lamps are being recommended as they prevent disastrous results when one happens to observe a lamp which is directly overhead or well within the range of vision.

In a great many cases of industrial lighting, where the physical conditions are such that indirect lighting may be used, it has been applied and the results have been very satisfactory. However, the greater percentage of industrial plants have such a great amount of moisture, dirt, soot, and oil that this system cannot be employed and it will, therefore, be some time before the use of the open reflector can be abandoned.

Many kinds of small diffusing globes and even opaque metal cups to be used over the lamps in connection with the open reflectors

have been designed and manufactured. They have been used to a certain extent but have not been tried out sufficiently to warrant any definite comment up to the present time.